



Safety supervision of water structures in the Czech Republic



MINISTRY OF AGRICULTURE
OF THE CZECH REPUBLIC

Dear readers,

since the time of the first water ponds many water structures have been built serving various purposes in the Czech Republic. These water structures fulfil different water supplies essential for inhabitants of our country such as water supply, industry, agriculture and lot of others. First of all, concerning the dams, their main purposes are flood protection, drought prevention and also helping to retain water in the country.

However, these water structures can also cause wide loss of property, environmental losses and risk of loss of life. The safety of water structures is provided by the safety supervision dedicated to the authority of my government department. The aim of this safety supervision is to prevent emergency situations, which may endanger stability and operational reliability of water structure.

This publication, presented by the Ministry of Agriculture, brings you some basic information on water management and focuses on the safety supervision of water structures.

I will be pleased if the information here provided helps you to create a basic idea on how this matter is managed in the Czech Republic.



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Orlik dam

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Hracholusky dam

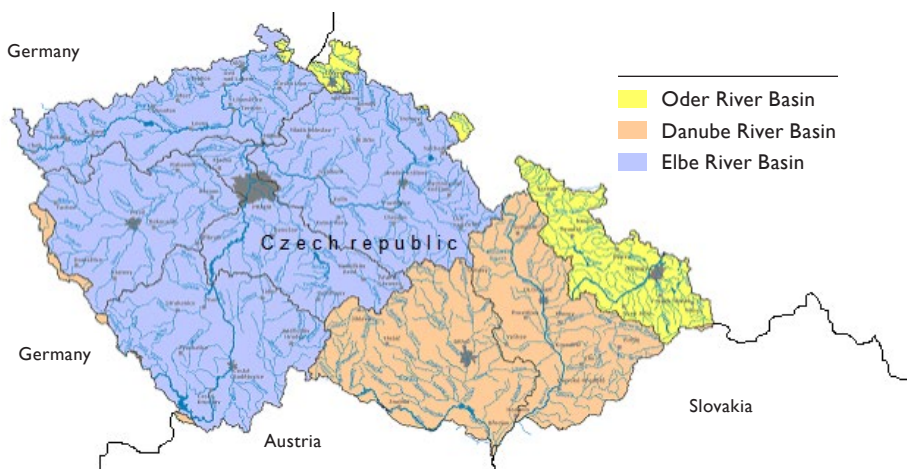
I. Basic hydrological situation in the Czech Republic

The area of Czech Republic is 78,870 km² and the country belongs to the inland countries. There are almost no inflow watercourses, and large amounts of water flows out of our territory. The volume of annual precipitation in the Czech Republic is 54 billion m³, however, most of this evaporates or runs off. On an average year 28.8 % of the precipitation (approximately 15.6 billion m³) runs off. Part of the runoff supplies groundwater sources, on an average 1.4 billion m³ annually. The precipitation is spread locally and distributed throughout the year.

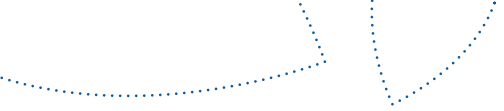
The maximum monthly precipitation occurs in June and July, the minimum occurs in January and February. The Žatec region (with 410 mm annual precipitation) is one of the driest regions; the highest an-

nual precipitation is in the Jizera Mountains (1,700 mm). The measured precipitation differs in individual years and catchment areas.

The surface of the Czech Republic is mainly situated in altitudes between low highland (300–600 m a. s. l.) and upland (600–900 m a. s. l.) and situated in catchment area of main European rivers: the Elbe (carry off a water from 63.5 % of the territory), the Danube (carry off the water 27.2 % of the territory), and the Oder (carry off the water from 9.3 % of the territory). Rivers run off to the North Sea, Black Sea and Baltic Sea. The watershed boundaries between the catchment areas of the Elbe, Danube and Oder meet together in only one point at the Králický Sněžník mountain.



International river basins in the territory of the Czech Republic



System of watercourses with the total length of 99,500 km is created by the main watercourses (16,300 km) and the small watercourses (83,200 km).

The major part of the most important rivers such as Vltava, Elbe and Morava has been regulated in the 19th century and in the beginning of the 20th century. Part of the small watercourses were technically regulated after the World War II. The length of these small regulated watercourses was approximately 16.2 thousand km, and the main purpose of this regulation was water supply for agriculture. Statistically, the average density of watercourses without artificial changes is 0.96 km/km² which is considered as convenient value in case of the Central Europe climate.

Water surface areas in the Czech Republic consist mainly of artificial water reservoirs, but also some lakes, wetlands and pools. There are a few natural water surface areas; lakes cover approximately 50 ha and wetlands only 17.8 ha. However, the majority of all water surface areas are represented by artificial water reservoirs (76,900 ha), which

are mainly associated with fish farming ponds covering 52,900 ha. The total area of reservoirs impound by large dams is also significant.

The ground water exists in the low abundant ground water zones. These non-uniformly distributed zones cause serious problems. The most important ground water zones are situated in the central part of North Bohemia and in East Bohemia and covers 12,500 km². Another significant ground water zone is in the South Bohemian basin.

In the last twenty years, the country has had to deal with nine disastrous floods which caused 135 fatalities and property and infrastructure damage of 190 billion CZK. Drought has occurred three times during this period and the corresponding damage has been estimated to be 20.6 billion CZK.

More detailed information has been published by the Ministry of Agriculture: "In brief about water in the Czech Republic" and "Report on water management in the Czech Republic". Both available at www.eagri.cz webpage.



2. Water management

2.1. Administration of the water management

The policy of water management in the Czech Republic is creating conditions for sustainable management to harmonize requirements of water supply and requirements of source water protection, both carried out by protective measures to reduce flood and drought consequences.

The main issue of water management is to guarantee the water supply for inhabitants, industry (especially for power plants) and agriculture. Secondly to provide available water sources, reduce extreme hydrological events (flood and drought) and to improve safety of water structures (especially ponds and dams).

Securing sufficient, good quality water supply in the Czech Republic is undertaken by state-owned enterprises, state authorities and ministries.

The Act. No. 2/1969 Coll., on establishment of ministries and other bodies of central government of the Czech Republic; Act. No. 254/2001 Coll., the Water Act; and the Act No. 305/2000 Coll., the River Boards Act are the most important legal base for control and organization of the water management.

The water authorities execute the state administration:

- ministries (the Ministry of Agriculture*, Ministry of Environment*, Ministry of Defence, Ministry of Transport – represent central water authorities)
- regional authorities*
- authorities of municipalities with extended jurisdiction*
- military zone authorities (in military zones only)
- municipal authorities

*Note: * these authorities have an important jurisdiction in the water management field.*

Administrators of main watercourses and selected small watercourses:

- Vltava River Board, state enterprise, residence in Prague
- Morava River Board, state enterprise, residence in Brno
- Elbe River Board, state enterprise, residence in Hradec Králové
- Oder River Board, state enterprise, residence in Ostrava
- Ohře River Board, state enterprise, residence in Chomutov

Other administrators of small watercourses:

- Forests of the Czech Republic, state enterprise
- national parks administration, (at the territories of national parks)
- Ministry of Defence of the Czech Republic (in military zones)
- municipal authorities (for short parts of the watercourses in the built up territory of the municipality)
- legal persons or natural persons (exceptionally)



A building of the Ministry of Agriculture in Prague

The safety supervision of water structures is under the authority of the Ministry of Agriculture. All river board authorities and Forests of the Czech Republic are established by the Ministry, providing a methodical guiding of these enterprises. In addition to this the Ministry, as the central water authority, methodically governs subordinated municipal authorities in regards to the water management.

2.2 History of the water management

The development of the water management in the Czech Republic can be divided into four time periods according to the social and economic state. Since these eras, a large number of water structures with different purpose and importance have been built.

At the beginning the water sources supply all water requirements in the natural state or with only small regulation. The water requirements for industry, agricultural and inhabitants did not exceed the local water resources. The excessive usage of water sources was not necessary at these times. Water structures and sources were invested by local municipalities, cooperatives or by country. First period of such development was until the World War II.

During the second period water requirements increased and could not be supplied without coordination of independent subjects (catchment authorities, etc.). A water authority was established and managed water requirements together with water sources. Water sources were managed in a multipurpose way and water management was adopted as a single field of study. Large dams, other water structures and regulation of entire territories were made during this period. Major increase of water requirements was for industry, inhabitants, electricity supply and increase in production. Water

sources were regarded as a common commodity without consideration of the impact on the natural environment. This period ended at the end of the 1960s.

In the third period the potential for excessive usage of water sources ended and the rationalisation of water management activities started to be more important. In addition to this, a more sensitive attitude to the natural environment was taken into account by people and the development and management of water resources. This period started in the beginning of the 1970s. Water structures were grouped to systems, and usage of water sources started to be complex.

The beginning of fourth period was in the 21st century and it is characterized by lowering water requirements. The environment protection, especially water sources become the key part of water management. International cooperation starts to be necessary to face the increasing impacts of climate change.

Štěchovice dam on
the Vltava river



2.3 Report on the large dams in the Czech Republic

The experience obtained with the construction of small ponds enabled the construction of the Jordán dam in 1492. This embankment dam is 20 m high and the stored capacity of reservoir is over 3 million m³. Also the dam of Máchovo jezero was constructed situated on the south of Prague with stored capacity of 6 million m³. Also, the system of South Bohemian, consisting of small dams and ponds constructed during the 16th century was unique, for example the pond Rožmberk has a reservoir with 40 million m³ on an area of 720 ha.

In the late 19th century five dams, two of which were masonry, were built in our country. The maximum height of these embankment dams was less than 18 m above their foundation and their operable storage capacities have reached 1.6 million m³. In 1896, approximately 2 km from Mariánské Lázně, a masonry dam was put into operation. The original dam height was 15.9 m. It is the oldest masonry dam in our country. The dam was rebuilt and heightened in 1912, the current capacity of the reservoir is 0.28 million m³.

The increase of water requirements for industry caused an increasing number of dams to be constructed. Between 1890–1920 fourteen masonry dams and three embankment dams were built. The maximum height of the masonry dams reached 53 m above the foundation (the dam Janov), and maximum height of

embankment dam 22 m (the dam Souš). The capacity of the maximum reservoir reached 9 million m³ (the dam Les Království).

Between 1920–1945 six embankment dams and nine masonry or concrete gravity dams were constructed. Also during this period, the embankment dams constructed before 1916 were completely reconstructed. The maximum heights of the concrete dams reached 60 m, while heights of the embankment dams were still less than 25 m. The maximum capacity of the largest reservoir built in this period exceeded 130 million m³ (Vranov dam).

After the World War II, gravity dams were the main type of dam constructed. First masonry dams were built, but later concrete dams prevailed. World War II caused a recession in the number of dams constructed but between 1950–1990 there was again a boom in the construction of dams. More than 80 embankment dams and 13 concrete dams were built. The maximum dam height in this period was the 100m (Dalešice dam), the maximum stored capacity exceeded 700 million m³ (Orlík dam) and the largest reservoir area was 4,870 ha (Lipno dam).

After the 1950s the State Authorities started to influence and control dam designing and constructing by river basin state enterprises and by municipal authorities for water management. Dam operation, safety supervision and also water management improved. Geodetic measurement of the dam body, measurement of pressure and seepage quan-

tity were commonly adopted and measuring devices were more accurate.

Political, economic, and social changes after 1989 caused the rundown of designing and constructing of large water structures. The transformation of the industry and increased demands of environmental protection also help this process. The last dam constructed was Slezská Harta finished in 1997. It is an embankment dam with height of 65 m above the foundation.

After the destructive floods in 1997 the Government of the Czech Republic decided to design and construct the Nové Heřminovy Dam. Construction of this dam will start probably in 2020. After finishing the dam body and other related flood protection measures, six thousand people in the upper part of Opava catchment area will be protected.

Preventively restrained localities for future construction of new reservoirs by water management plans were re-examined due to the expectation of unfavourable climate change impacts in future years. In that case, the most suitable localities for water supply systems are Pěčín and Vlachovice. The Government will discuss the future construction till 2018.

Specific morphological, hydrographic and hydrological situation in the Czech Republic reduce future use of water sources. This is a reason why the priorities of our water management are to retain and take good care of it. This approach is also supported by the ratio of the amount of natural water sources to the number of inhabitants in the Czech Republic. This ratio is less than the European average.



A visualization of Nové Heřminovy reservoir in its pre-construction phase.



Čelákovice weir on the Labe river

3. System of water structures safety securing

In the Czech Republic, the safety of water structures is controlled by the system of dam safety supervision, which is performed on two levels. The least important water structures are under the supervision of the owner, administrator or operator. It is performed in a self-managed regime. More important water structures are under the supervision of an independent, professionally competent legal person authorized by the Ministry of Agriculture. The control role is performed by the water management public authority.

3.1 History of the safety supervision

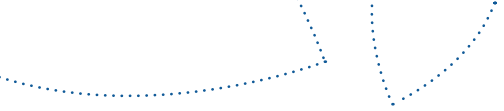
As one of the first legal regulations in water management, we can mention water act from 1870 “about how the water can be used, can be tied and how can we protect against it“. From today’s safety supervision point of view, the act included care representing necessary ways of the water structure operation. Controlled loading during the first filling, observation of the behaviour of the water structure, measurements of the temperature, vertical and horizontal deformations, seepages and ground water levels (hydraulic head) of the water surface were for instance parts of the care. From the same time is also Min-

istry regulation from 1894 on founding, managing, using and ending the operation of ponds.

The textbook about dam construction “Construction of water reservoirs” from 1911 has mentioned that: “Finished structures must be submitted to a permanent careful attention. It is important that even each very subtle change must be noticed in time and its cause evaluated”. There is also a book by Václav J. Štěpán from 1915 concerning the importance of the pond safety, which mentions “permanent surveillance of the state of the retaining structure and other parts of pond structures and careful observation especially after each flood”.

Significant failures of the water structures in 1853 and 1870 and especially the fatal failure of the Bílá Desná dam in 1916, which caused losses of tens of human lives and great damage on properties, contributed to the development of dam surveillance.

In the beginning of a very intensive dam construction after World War II the department for functions of the built-up water structures was established in 1953 in the Water Management Development Centre. Employees of the department developed new methods of observations and measurements of the phenomena



important for the dam safety. At the end of 1955 the Central Administration of Water Management published the first instructions for observations and measurements on dams.

Systematic observation and measurement on the dams gradually started and an expert engineering activity gradually developed into the form of today's dam safety supervision. Thus, an imaginary cornerstone to the contemporary system of the safety supervision was laid in 1955.

The basic differences between earlier and today's approach to the water structures safety system can be simplified so that earlier observation and measurement was more focused on the gathering the information about their behaviour. While nowadays safety supervision on the water structures is considered to be a complex engineering activity, which involves many disciplines and activities. This is mainly due to the protection of the public interests with its focus being on the evaluation of the structures safety and operational reliability, to prevent failures of the structures and choosing optimal remedial measures. The aim is to reduce to its limit the possibility of the water structure failure. Dam breaks usually cause economic losses on the structures itself as well as in the downstream flooded area and represent a great threat to the population.

Despite the above-mentioned references, dam safety supervision as such, was

for the first time mentioned in the Czech legislation in years 1973 and 1974, namely Act No. 138/1973 Coll., On Waters (Water Act), and Act No. 130/1974 Coll., On State administration in water management. An implementing regulation of these acts was issued by the Ministry of Forestry and Water Management under No. 62/1975 Coll. on the safety supervision on some water structures and on safety supervision of public authority on them.

A more precise definition of the safety supervision, categorization of the water structures, specification of the duties for each of the categories, the role of the public authorities, including sanctions if the safety supervision is not performed accordingly to legislation, was set by a new water act in 2011 (Act, No. 254/2011 Coll.).

Recent floods, particularly the catastrophic floods in August 2002, have proved that those water structures where safety supervision is properly carried out were able to withstand the extreme discharges and structural loads from these floods. The importance of the safety supervision and meaning of its further development and improvement has thus been proved.

3.2 Contemporary legislation

After adoption of the new Water Act in 2001, a new implementing regulations on the safety supervision was also issued. In addition to this, there are some general

obligations on the owners of water structures resulting from the Building Act, as water structures in the Czech legislation are considered to be constructions as such.

Nowadays, the following legislation applies:

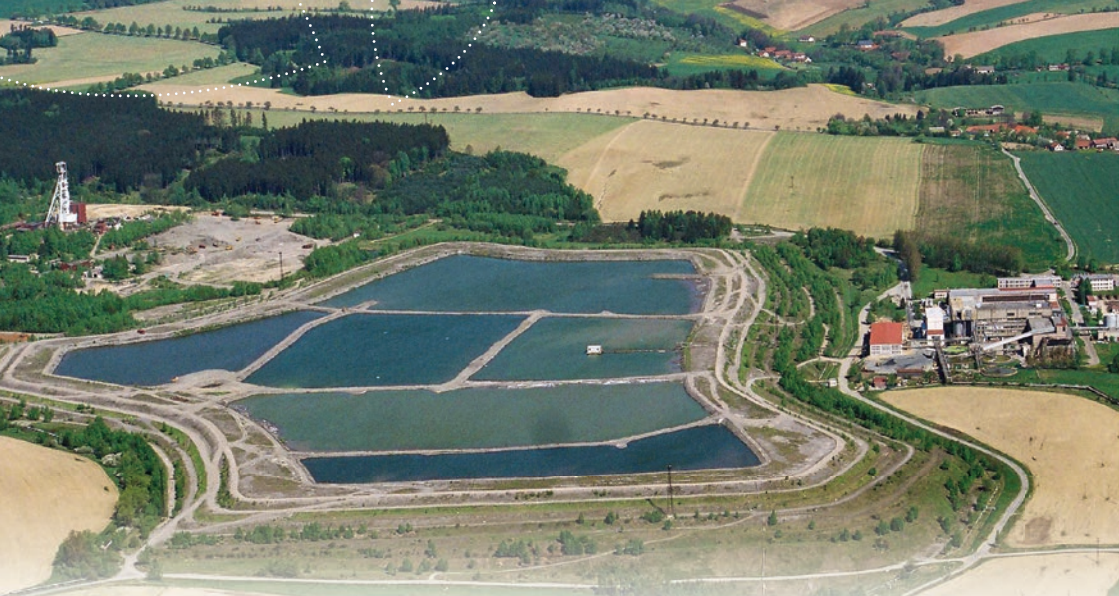
- Act No. 254/2001 Coll. on Water (The Water Act)
- Regulation No. 471/2001 Coll., on the Safety Supervision on the Water Structures
- Regulation No. 590/2002 Coll., on the Technical Requirements for Water Structures
- Regulation No. 216/2011 Coll., on the Requisites of Manipulation Rules and Operating Rules of the Water Structures

A high number of water structures are located in urbanized areas with relatively high density of population. These structures represent potential risk to inhabitants and properties. Therefore, apart from other water management tasks, the Water Act deals with the safety of water structures with a focus on the safety supervision system. The fundamental legal implementation document for the safety supervision is the regulation of the Ministry of Agriculture No. 471/2001 Coll. on the Safety Supervision on the Water Structures. This regulation defines water structures which are subject to safety supervision (specified water structures), defines criteria and the process of their categorization,

sets down the range and frequency of the supervision according to its category and the phases such as preparation, construction or operation of the structure. Performing safety supervision according to this regulation ensures the control of their safety and operational reliability.

Specified water structures are determined as follows:

- a) dams, dikes and weirs, with exception of cross structures in riverbeds of watercourses and adjacent areas with height from the toe to the crest smaller than 1 meter and the maximum volume of retained water does not exceed 1 000 m³; or solid and fixed cross water retaining structures in riverbeds of watercourses with solid spillway crest over the bottom of the downstream river bottom up to 1.5 m,
- b) flood protecting structures,
- c) tailings dams,
- d) hydro-technical galleries and tunnels,
- e) structures for navigation purposes built in watercourses riverbeds or on their banks
- f) structures associated with hydro-power if they retain water, except for cross structures under a) above.
- g) other structures serving to retain water, except for reservoirs completely buried under the surrounding area without a retaining element, mud pools, lagoons, blind stream branches, water conduits and water tanks, sewer network and recreation pools.



The majority of tailings dams is located in the northern region of the Czech Republic

The first appendix of Regulation No. 471/2001 Coll. contains a general criteria list as an illustrative description of the range of potential damage of each water structure category. The second appendix represents a list of phenomena observed in the process of safety supervision according to the type of water structure. The third appendix presents different kinds of evaluation documents such as partial reports, summary reports, overall reports, stage reports, summary stage reports and their individual content.

Regulation No. 471/2001 Coll. is based on experiences gained especially on large dams and from the application of previous regulation from 1975 which were valid, together with Water Act No. 138/1973 Coll., until a new water act came into force on the 1st of January 2002.

Another legal document is Regulation of Ministry of Agriculture No. 590/2002 Coll.,

on the Technical Requirements on Water Structures, which specifies technical requirements of the chosen design parameters. It contains general requirements, which must be taken into consideration during the preparation and design as well as during the construction of the water structure. These requirements come mainly from the water structure purpose and other related demands such as mechanical durability and stability, operation safety, protection of structures against frost, ice and debris. Other important factors are geological, morphological and hydrological conditions of the locality. Foundation and design of the structure must meet special requirements on stability and durability. These regulations further lay down general, as well as specific, technical requirements for different water structures (dams, dikes, water reservoirs, flood protection structures, tailings dams etc.). It sets up demanded

margins of safety of water structures during hydrologic floods according to its category.

The final legal document to be mentioned is Regulation No. 216/2011 Coll. which deals with the requisites – content of handling and operating regulations of the Water Structures. It lists obligatory contents such as information about the owner, technical data about the structure, fundamental principles of the handling with water, instructions for handling in emergency situations and performing safety measures etc.

Methodical directions are documents which do not have the character of the law or regulation. In the Czech Republic, the methodical directions are only internal, not obligatory instruction. It becomes obligatory only in the cases when certain legal document make an explicit mention of the methodical direction.

The Ministry of Agriculture elaborated the methodical direction No. 1/2010 on the safety supervision on the water structures. It further describes methods and conditions of water structures categorization, proper performance of the safety supervision on the structures belonging into IV. category, treatment and maintenance of vegetation on earth-fill dams and performance of the supervision of the flood protection on linear structures.

The Ministry of Agriculture has also got an internal methodical direction con-

cerning the proceedings and conditions of the authorization of legal subjects to perform safety supervision on water structures and to elaborate on the classification of water structures concerning categorization.

Other methodical directions on the flood protection are published by the Ministry of the Environment of the Czech Republic as this ministry is responsible for this particular issue. These methodical directions provide a unified approach among water structures owners, administrators of watercourses and public authorities, dealing with dam break floods which can happen during the operation of water structures. There are three different kinds of dam break floods: failure of main structure, failure or malfunction of appurtenant works, emergency actions taken during emergency situations (they are further described in the chapter 4). Methodical directions further set up 3 levels of flood warning criteria on the structures in case of a risk of dam break flood occurring (also in details described in the chapter 4).

Also, technical standards have become an important element ensuring safety of water structures in the Czech Republic. Czech technical standards are not obligatory unless it is quoted in legal regulations. Their use is voluntary; however, they are considered to be qualified recommendations which ensure fulfilling of requirements on technical quality, functionality, safety and protection of the environment.

Standards concerning water structures which influence water structure safety (ČSN = Czech technical standard)

Designation of the standard	Name of standard
ČSN 75 0255	Calculation of wave effects on water structures
ČSN 75 2020	Asphaltic layers for hydro-technical structures
ČSN 75 2310	Embankment dams
ČSN 75 2340	Designing of dams - Basic parameters and equipment
ČSN 75 2405	Water management analysis of reservoirs
ČSN 75 2410	Small water reservoirs
ČSN 75 2601	Small hydro-power plants - Basic requirements
ČSN 75 2935	The Safety assessment of hydraulic structures during floods
ČSN 75 3310	Tailings dams

3.3 Types of water structures which are subject to the supervision

Water structures which are subject to safety supervision can be divided into following groups:

- small water reservoirs with low embankment dams
- protective dikes
- tailings dams
- weirs and sluices
- classic masonry, concrete or embankment dams
- conduits (especially long hydro-technical galleries)

Each of these groups has its specifics that must be taken into account during their observation and performance of the safety supervision.

The most numerous water structures in the Czech Republic are **small water reservoirs** built for fish farming (ponds), they represent a significant part of the Czech landscape. Their construction started in the 12th century and since the Middle Ages 25 % of them have preserved. The total number of small water reservoirs is approximately 24 000. The primary reason for their construction was the fish farming. Later the purpose of water accumulation for water mills and of a water source for various branches followed. They also fulfil recreational and landscaping functions.

Approximately 1 200 weirs help to create sufficient water retention for energy, transportation and water usage. Nowadays lots of weirs are being reconstructed for the needs of small hydro-power plants and the construction of fish ways.

Due to the gradual urbanization of the landscape flood protection was needed. To ensure the reliable flood protection there is 2 100 km of major dikes and other elements. A few hundred retention reservoirs (dry reservoirs and polders) were built on the local level as a protection against flash floods. Most of them are in the fourth safety category but it is not an exception if they are in the second or third category.

With the development of the chemical and energetic industry and mining of minerals the demand for storage of liquid waste from power plants, heating plants and factories occurred resulting in the construction of tailings dams. There are approximately 35 tailing dams in operation that are subject to safety supervision.

Dams belong to the water structures with the biggest contribution to water management and society. Dams were

constructed especially in the 21st century. By damming of watercourses large water reservoirs were created which serve different water management purposes such as flood protection, increasing of the discharge, water supply of inhabitants, industry, agriculture, production of electric energy or for recreational purposes. Altogether 180 dams were constructed and 118 meet the criteria for large dams according to the International Commission on Large Dams - ICOLD. Very important are especially those multi-purpose dams with significant retention volume and possibility of its increase before the flood discharge. Most dams on one watercourse are on the Vltava river, so-called Vltava cascade.

Other water retaining structures represent a less numerous group, nevertheless they are important for the navigation on the waterways (especially sluices on the Vltava River and the Elbe River) or to ensure the transfer of water from one river basin to another where more water is demanded (Podkrušnohorský channel, Morávka – Žermanice channel, Želivka – Praha hydro-technical gallery and many others).

Water structures according to safety supervision category

(state by 1st January 2017)

category	type of the water management structure							total sum
	dam	dry reservoir	weir	tailing dam	dike	Hydro-power plant	others	
I.	28	0	0	0	0	0	0	28
II.	51	0	3	7	7	1	2	71
III.	178	29	37	18	65	11	4	341
total sum	257	29	40	25	72	12	6	441

3.4. Categorization of water structures

Danger for the area downstream of the water structures generally result from:

- a) a mere existence of water retaining structure
- b) a technical state of these water structures and probability of their failure

Categorization of a water structure into a category is carried out according to losses from a potential failure of the structure resulting in a dam break flood wave. The amount of the losses is expressed by the damage potential number. The value of the damage potential depends on the degree of danger to human life, property, losses from dam operations and danger to the environment resulting from both flooding of downstream area and end of operation of the structure itself. The technical state of the water structure is not considered during the process of categorization. Usually the categorization on new structures is carried out in the phase of its preparation.

Categorization of water retaining structures was adopted in the Czech Republic in 1975. At that time, the first list of water structures of I. – III. category was elaborated. All others water retaining structures were automatically included into category IV.

Due to the changes in the Czech Republic in the following years the first round of categorization was revisited in years 1992 and 1993. This led to some changes

in the categories mainly associated with structures in categories III. and IV.

Only a professionally competent legal person authorized by the Ministry of Agriculture can perform a safety supervision on structures belonging to categories I. up to III. and to prepare an elaborate category report (based on this document the water management authority will include the water structure into one of the categories). If authorized legal person is an owner of the water structure I. or II. category, it cannot carry out the safety supervision by itself.

Ministry can give the authorization only to a legal person with professional, personal and material equipment which is prerequisite for qualified performance of the safety supervision.

Accordingly to the category of the water structure, legislation (Water Act, Regulation on the safety supervision) sets down the scope of structure owner obligations and rights. Overview of observed phenomena is listed in the appendix of above mentioned regulation.

Criteria for including water structure into appropriate category:

Category I

- thousands to tens of thousands of inhabitants are in danger and great losses of human lives are expected
- huge damage on the water structure itself, the remedy is very complicated and expensive

- in the downstream flooded area, a great damage on residential and industrial structures, roadway and railway network and other water structures is expected
- losses caused by putting the water structure out of operation, (interruption of industrial production, transport etc.) are very high and difficult to be compensated
- environmental losses are high, they exceed importance of the region, economical results influence the whole state

Category II

- hundreds to thousands of inhabitants are in danger and losses of human lives are expected
- large damage on the water structure itself, the remedy is complicated and expensive
- in the downstream flooded area damage on residential and industrial structures, transport network and other water structures is expected
- losses caused by putting the water structure out of operation, (interruption of industrial production, transport etc.) are significant
- environmental losses are on the regional level

Category III

- tens to hundreds of inhabitants are in danger, losses of human lives can occur
- damage on the water structure itself, the remedy is possible

- in the downstream flooded area damage on residential and industrial structures, transport network is expected and other less important water structures can be endangered
- losses caused by putting the water structure out of operation, (interruption of industrial production, transport etc.) are fully compensated
- environmental losses are on the local level

Category IV

- losses of human lives are not expected
- damage on the water structure itself, the remedy is possible
- in the downstream flooded area is expected little damage
- losses caused by putting the water structure out of operation are insignificant
- environmental losses are on the local level

As it was already mentioned, the basic principle of the categorization is the determination of number of human lives in danger and amount of damage (damage potential) which would occur in case of the dam break flood. For the damage potential determination, it is necessary to know the parameters of the peak discharge of the dam break flood wave and its propagation in the downstream endangered area. Propagation depends on the gradient of the watercourse, on the shape of the valley, urbanization and vegetation.



Trees on the dams of historical ponds are important landscape features

Potential damage in flooded area is determined for the profile where the dam break flood discharge decreases to the value of the hydrological 100-year flood.

Damage potential (P) consists of the following parts:

- human lives in danger
- direct damage – on the water structure itself
- direct damage – in the downstream flooded area
- indirect damage - in the downstream flooded area
- losses caused by putting the water structure out of the operation

All parts of the potential damage are classified with point-values. Total value – total damage potential is the basis for setting the structure into the category. Range of the damage potential for each category is as follows:

$P < 15$	category IV
$15 \leq P < 200$	category III
$200 \leq P < 1500$	category II
$P \geq 1500$	category I

Quantification of each part of the potential damage is calculated individually according to the distance from the water structure and according to the dam break flood wave parameters, especially the depth.

The process of the categorization of the water structure requires the collection of numerous water structure data and land use information. It is a very responsible process, entrusted only to a several experienced employees who are professionally skilled and using the necessary methodology.

Categorization of the water structure also influences the technical requirements for the design and construction. For dams on the water courses there is a required margin of safety which is given by the probability of exceeding the control flood wave. The period of the control flood wave, and the respective margin of safety, is prescribed in the regulation No. 590/2002 Coll. and correlates with the structure category and presumption of human lives in danger. This affects the requirements for the constructed spillway capacity. This obligation applies for new structures as well as for already existing structures. The Safety assessment of water structures during floods is prescribed in detail in the Czech technical standard 75 2935.

3.5. Scope and frequency of the safety supervision

Scope and frequency of the safety supervision is prescribed in the regulation No. 470/2001 Coll. In accordance with this regulation safety supervision is considered already in the preparation phase and subsequently it is performed in the phase of construction, or reconstruction in case of older structures, testing phase and in the operation phase. Specific content of the supervision results from technical characteristic of the water structure, prognosis of the future operation, the most probable failures (both physical failure and system failure) and risks coming out from the structures existence generally.

Methods, scope and frequency of the safety supervision depend on:

- a) the category of the water structure
- b) the phase of the water structure
- c) the type of the water structure with respect to operational conditions and loading states

For **dams**, a construction arrangement, static effect and a quality of a bedrock is important. Important high dams and large reservoirs are usually in this group. An automatic monitoring of observed phenomena is gradually being installed on these dams. Data are transmitted to the control room of the structure and further for final overall evaluation. Methods of the monitoring, frequency and range of the measurements and requirements concerning data accuracy differ according to individual type of the water structures. Dams in the I. category are under strictest supervision where visual observation is done daily and inspection with the presence of the water management authority is at least once a year.

Tailings dams are very specific water structures. Construction arrangement of systems of dikes is often a combination of basic embankment dikes from local materials with their gradual increasing using sedimented material. Reservoirs of tailings dams are gradually filled and afterwards their operation is finished. Next phase of the tailings life is their reclamation when they stop to be

considered as a water structure. During the existence of these structures the effective load is constantly changing and this specific feature must be implemented in the safety supervision.

Small water reservoirs, mostly of the category IV, are represented usually by historical ponds. Only about 200 most important small water reservoirs are classified in the III. category. Execution of the safety supervision is based on monthly observing tours with focus on the technical state of the structures. Measurements are incorporated only for individual purposes, e.g. measurement of the water seepage, of the level of the dam crest or local deformations. Investigation of the bottom outlets (often timber on the historical ponds) is

quite frequent. Also, controlling of the spillways is important as their unsuitable state is often a cause of the overtopping and failure of the structure.

Experience shows that safety supervision is not often carried out properly on the VI. category structures and occasionally also on the III. category structures. This finding is confirmed by the fact, that almost every year two to ten failures of the small water reservoirs occur. These failures can cause major damages and sometimes a threat to human lives as well.

In cases of the rehabilitations of the water structures which can often be initiated by a structure failure or accidental situation the categorization is needed



Safety supervision of a small dam can be a little adventure as well

to be done again. This obligation is on the owner of the structure. If there are some changes in the downstream area, most often an increase of a density of population, categorization process can be demanded again by the water authority.

Problems are usually caused if the vegetation on the dikes and on its downstream side is not maintained properly. Another problem could be a missing documentation about the foundation and materials of the structure. Therefore, surveys and investigation are needed.

On movable weirs and sluices in comparison with other water structures, steel structures dominate and retain the water. Many parts of the structure are most of the time under the water. Changes of the shape and stability of the river bottom on upstream and downstream sides are important. Requirements on measurements on solid structures and on movable steel structures are different.

Water conduits especially long hydro-technical pressure galleries (e.g. gallery-conduit of drinking water for Prague from the water structure Švihov is 52 km long), often led under the terrain surface with overlaying formation with thickness of approximately tens of meters. They pass through different geological and hydrogeological formation. Methods of monitoring of their technical state and operational safety are based on various measurements, e.g. of water seepage, deformations, changes in pressure in

the conduit, changes in the groundwater flow along them, or the control of the territory above their route.

Very important are inspections during outage periods, when normal operation is interrupted. During the inspections, the state of the conduits is not assessed only by visual observation but a whole range of the measurements are performed, e.g. seepages, deformations of the constructions, changes of mechanical qualities of used materials and their aging, photo documentation is acquired. However due to operational and organizational reasons, it is only possible to organize these overall inspections of the conduits at long time intervals of tens of years.

Dikes along the watercourses built as flood protection have usually a similar structure as the dikes of the small water reservoirs. Problems of the safety supervision are increased as the dikes are usually long linear structures and controlled evaluating operation cannot be performed, similarly as in the case of dry reservoirs. Evaluation how well dikes were constructed and how they are able to resist the load is proved during the first flood.

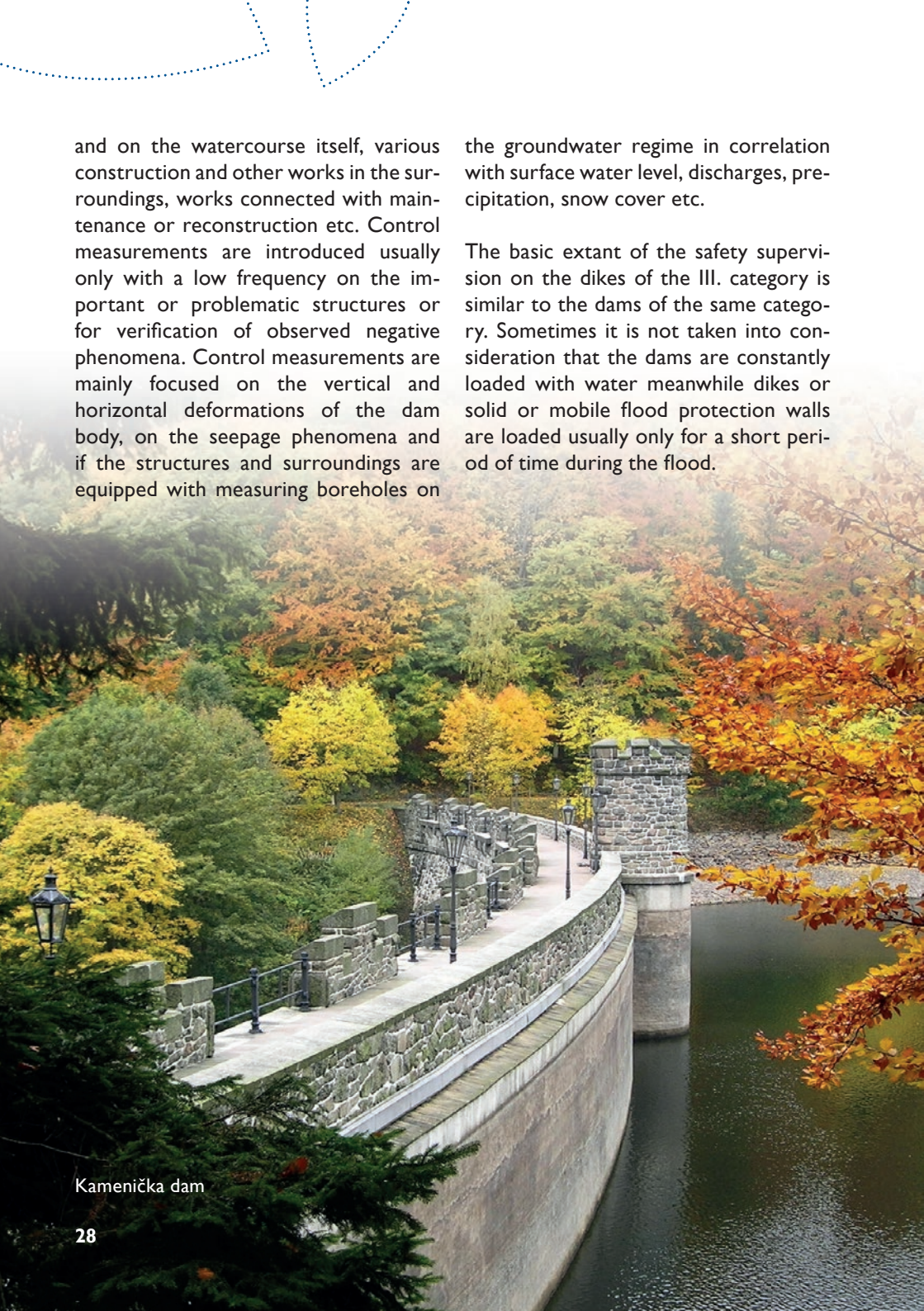
The usual performance of the safety supervision is based on the regular inspections with visual observation. Observed are deformations, the state of the vegetation and activity of animals on the embankment dikes, third sides interventions, changes in the area along the watercourse

and on the watercourse itself, various construction and other works in the surroundings, works connected with maintenance or reconstruction etc. Control measurements are introduced usually only with a low frequency on the important or problematic structures or for verification of observed negative phenomena. Control measurements are mainly focused on the vertical and horizontal deformations of the dam body, on the seepage phenomena and if the structures and surroundings are equipped with measuring boreholes on

the groundwater regime in correlation with surface water level, discharges, precipitation, snow cover etc.

The basic extant of the safety supervision on the dikes of the III. category is similar to the dams of the same category. Sometimes it is not taken into consideration that the dams are constantly loaded with water meanwhile dikes or solid or mobile flood protection walls are loaded usually only for a short period of time during the flood.

Kamenička dam



4. Emergency situations of water structures and main causes of failures

Emergency or extraordinary situations of water structures are caused by different reason. They can be caused by both natural phenomena or human activities. The most probable natural phenomena for the Czech Republic are as follows:

- hydrological floods
- extreme weather phenomena (e.g. high or low temperature, windstorm, local cloudburst)
- landslides, rock collapses, avalanches, etc.

The emergency situations caused by human activities are mainly connected with following phenomena:

- dynamic load from the demolition work or construction work, load from traffic nearby of water structure
- changes of both surface water and groundwater regime
- changes of purpose or operation conditions of water structure (connected with fast increasing or decreasing of the water level in reservoir)
- vandalism, sabotages, attacks during war

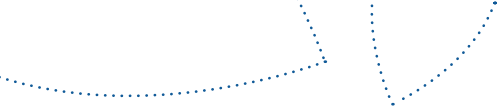
Untreated emergency situation can lead to dam collapse (global failure of dam

body) resulting in uncontrolled outflow of water from the storage, so-called dam break flood.

Generally, there are two types of flood, the hydrological flood and the dam break flood. The hydrological flood is defined as a temporal raising of level of water in stream channel, which can result in flooding nearby area of river. The hydrological flood is caused by nature phenomena.

The dam break flood is defined as a flood caused by artificial phenomena, e.g. during the building of new water structures, operation of existing water structure or its reconstruction. The dam break floods can be caused by failures as follows:

- failure of main structural part of dam body, so-called dam break flood of type 1
- failure or malfunction of appurtenant work (bottom outlet, emergency spillway), so-called dam break flood of type 2
- emergency actions taken during emergency situations in a point of dam body stability – controlled emptying of water reservoir, so-called dam break flood of type 3



Dam break flood is described by hydrograph (discharge vs. time). The hydrograph shows the beginning of the flood, rising limb, peak discharge, falling limb, time of dam break flood and the total volume of water.

Time of the dam break flood is defined as an interval between rising limb and falling limb according to the limit discharge. Generally, the limit discharge for type 1 is one-hundred-year flood discharge. For both type 2 and type 3 the limit discharge is chosen according to the capacity of downstream river channel. If the downstream capacity is not determined the limit discharge is chosen according to the flood warning criteria of the nearest gauging profile.

Determination of parameters for dam break flood type 1 is, for embankment dams, mainly performed by mathematical simulation of dam body erosion. The results of such a simulation depends on various factors such as, initial water level at the reservoir, reservoir inflow, type of failure, design situation, material characteristics, structure dimensions, downstream channel capacity, etc. Multiple scenarios with lots of variants is necessary.

Determination of the parameters for both dam break flood type 2 and type 3 is much easier than parameters for type 1. The scenario usually represents controlled (type 3) or uncontrolled (type 2) emptying of reservoir.

The differences between the hydrological flood and dam break flood, besides

their main cause, are in probability of their occurrence and their parameters (mainly lag time).

While probability of occurrence of the hydrological floods is defined approximately by reversed value of the time of their N-year cycle, where N is usually between 1 and 10^4 . Then the probability of global failure of water structure is much lower (assuming good technical condition of water structure). On the other hand, consequences of dam break flood (type 1) are much more disastrous. The consequences of both type 2 and type 3 are analogous to consequences of hydrological flood.

The area, which is affected by the flood wave, is the so-called flood zone. The method for determination of the flood zone is strongly depending on a type of flood, because of the different characteristics of flow. Basic input for the determination of the flood zone is the geodetic data, which is in general the most expensive item of the solution.

The first step, during the determining of a flood hydrograph for type 1, is to detect weak spots of the structure. This can be done with use of safety supervision reports, statistics of known failures, present experiences, etc. Then the failure scenarios can be defined.

In a case of type 1, the following failure scenarios are taken into account for earth dams and both masonry and concrete dams.

Statistically, the most frequent cause of failure of earth dams is overtopping as a result of insufficient capacity of emergency spillway or outlet structure. Praxis also shows cases of overtopping of tailings dam as a result of lack of technical discipline.

The second most frequent cause of failure is failure due to internal erosion. The most probable location of failure is along the joints between materials such as heterogeneous materials, concrete appurtenant works, pipelines, etc. The technology of construction of linear structures is also important aspect (bottom outlet, vertical walls, which do not allow proper settlement of the soil, etc.).

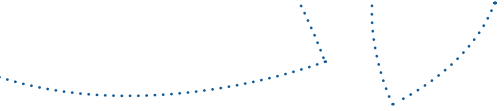
Other causes of failure such as earthquake or excess deformation are less probable. In this case, the probability of failure is determined with use of stability assessment, safety supervision reports and seismic activity mapping.

The most frequent theoretical cause of failure of both concrete and masonry

dam (type 1) is collapse of dam block (sliding, overturning, uplift). Second most frequent cause is internal erosion of sub-base.

The determination of type 2 always considers total malfunction of appurtenant works (gates, valves, lock, etc.). When there is more than one main appurtenant work, the malfunction is considered for the one with the most capacity. The determination of type 3 is performed with use of handling regulations and supervision guidelines.

The assessment of occurrence of dam break flood is directly connected with category of water structure and also with safety evaluation during the emergency situation (as a part of safety supervision). Basic document of dam safety supervision is so-called dam safety programme, which contains all the necessary information for safety supervision and also defines the categories for a degree of flood activity (analogous with hydrological flood categories).



An individual chapter of the dam safety programme states the characteristics of dam break flood. The second part of that chapter states what to do, when there is a threat of failure caused by dam break flood. The required action is divided into three levels – state of alert, state of danger and state of emergency.

Degree of flood activity 1 (state of alert)

Degree 1 is proclaimed when there is an unusual or uninspected development of measurements, monitored variables and other aspects related to safety of the water structure. All monitored variables with its limit values are listed in the supervision guidelines (dam safety programme document).

When the limit value is exceeded, the dam supervision authorities activates the procedures which are necessary for explaining of the anomaly.

One part of the supervision guidelines clearly states the organization structure of safety supervision performance. Periodical measurements and observation are the basic duty of the operating staff of water structure. When a limit value of measured variables appears, staff of the water structure has a duty to report it immediately to the main safety supervision engineer of the dam owner and authorized legal person preforming dam safety, who assesses the situation and propose other actions. If he cannot be reached, the situation has to be managed

by the formal assistant. If the formal assistant cannot be reached, the situation has to be managed by the operator of the water structure.

Degree 1 is proclaimed or revoked by main dam safety engineers based on evaluation of present situation (performing complementary measurements, etc.).

Degree of flood activity 2 (state of danger)

If unsatisfying situation persists, the impulse for proclaiming degree 2 is given to local authorities by the main dam safety engineers or staff of the water structure. Degree 2 is proclaimed based on complex analysis. The analysis consists of examining the measurements, monitoring data, surveys, any testing and other connected events for the purpose of excluding faulty data.

Degree of flood activity 3 (state of emergency)

Degree 3 is proclaimed when there is a real possibility of failure and dam break flood (this is reached when values of measurements reach to their critical point). The trigger for proclaiming degree 3 is given to local authorities by the main dam safety engineers or operator of the water structure.

Local authorities are activated for managing the evacuation of people in the flood zone and for performing the

emergency and warning actions. When the main dam safety engineers cannot be reached, the situation has to be managed by the operator of the water structure by using their own judgement.

Degree 3 is revoked by local authorities based on a request from the main dam safety engineers.

The third part of the chapter dam break flood in supervision guideline states both the emergency and warning actions which can be executed during degree 3. Those are for cases, when the main dam safety engineers cannot be reached and the operator must take action. Examples of the actions are as follows:

- ▀ immediately report about situation to local flood authorities and to fire brigade respecting the emergency

flood plans. In case of lack of time it is necessary, to warn directly both the natural and legal person imminently endangered,

- ▀ increase the resistance of the dam body against internal erosion using suitable component (without a sealing effect),
- ▀ lowering the water level in reservoir while respecting the limits of emergency drawdown (this action is not suitable when deformation of dam structure appears, e. g. local landslide or cracks of upstream slope).
- ▀ emergency increasing of surcharge storage of water structure, e.g. blocking the spaces in breakwater, building the temporary emergency spillway located in abutment, etc.





5. Failures of the water structures in the Czech Republic

As far as we know, there has been no large catastrophic failures of dams in the Czech Republic, with the exception of one – the failure of the Bílá Desná dam over 100 years ago. Other known failures of dam from the 19th century did not have as tragic consequences as the failure of Bílá Desná dam. In addition to this there has been a few losses of human lives which happened during flood situations on the dams of safety category III.

In 1854, the dam Pílská near town Příbram was breached due to major seepages. The dam body of Pílská Dam was 19 m high, total volume of reservoir was 1.9 million m³. The dam break flood wave resulted in big economic losses. However, the failure progression had been noticed in time and people were warned. Although two people died as a result of this failure.

In July of 1870 the dam Velký Rybník near Malešov was breached due to failure of the emergency spillway. The dam was 15 m high with 0.25 million m³ of total volume. Heavy rain caused the collapse of emergency spillway, which resulted in the failure of dam due to surface erosion.

The dam Bílá Desná was built in 1915 as a flood protection dam. The dam was situated in the Jizera Mountains (region Liberec). It was a homogeneous

embankment dam with 17 m high dam body. On September 18th 1916, the dam was breached, resulting in the death of 65 people. 33 housing buildings and 12 industrial buildings were destroyed and another 69 building were damaged. The failure occurred one year after an official substantial inspection. The cause of failure was insufficient geotechnical survey and a major mistake in the project documentation. On September 18th, local seepage had been observed. One hour later, after the unsuccessful attempt to manage the seepage, the dam started to breach near the bottom outlet. At this time, the technical possibilities did not exist to warn people downstream. There was also an indirect victim of the dam failure, the chairman of the substantial inspection committed a suicide after he had found out the range of consequences. The trial associated with this event lasted 17 years and finished with a verdict of acquittal for the accused persons. The failure of the dam Bílá Desná is the greatest catastrophe of a water structure in the territory of the present Czech Republic.

In April 1945, during the World War II, František Šíkula and his colleagues averted a big catastrophe. They sabotaged the attempt of the retreating German Army to place explosives on the Brno dam (dam body 120 m high, reservoir capacity



The current state of
the Bílá Desná dam breached
in the year 1916

21 million m³). Up to the present day there is a memorial in place there for remembering the courage of the dam keeper who saved lots of lives and prevented the huge material loss that would have eventuated.

During the floods in 1974, the failure of Hubačov dam (5.6 m high) near Mirošovice occurred, as a result of the dam being breached. Due to underestimation of the potential effects of the dam break flood and also incorrect coordination of local authorities during this event, five people died.

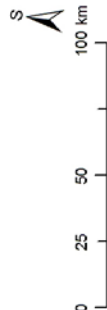
In the Czech Republic, hydrological flood represents the biggest safety threat for water structures. All dams affected by floods were exposed to extreme accidental load during the flood events in 1997, 2002 and 2013. During these flood events, some small embankment dams were breached or appurtenant works were damaged. Even without flood events, almost every year some emergency situation occurs. There are

approximately 2 to 5 cases where the breach of a water structure (IV. category) was without major consequences.

Dam reservoirs are not the only structures which are extremely loaded during a flood event. Also flood protection dikes are affected. During the extreme flood event in 1997, Morava river basin authority registered 64 failures, this was about 40 % of failures since 1965. In the territory of Oder river basin authority this was even 82.5 %.

Other significant issue is to secure the safety of the tailings dams. In 1982, the most significant failure of tailings happened. The tailings in Neratovice failed due to internal erosion. Luckily there were no lives lost in this accident.

Thanks to first-rate quality of safety supervision during the last tens of years, many local failures and weak spots have been identified. The resulting actions taken have averted the risk of possible catastrophes.



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